Martian/Lunar Analogue Research Station in India: Ladakh as a potential site

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Abstract

India has a rich geographical landscape apt for creating extra-terrestrial analogue habitats which are crucial for supporting prolonged space missions and addressing the challenges of sustaining human life outside of Earth. It is also imperative that these habitats are analogous, both in design and proposed locations, as accurately as possible for meaningful lessons and research. India has set ambitious targets for its space programme and that necessitates the construction of terrestrial research stations that can simulate extra-terrestrial conditions. We believe that this is an opportune time for establishing an analogue research station in Ladakh, benefiting a diverse group of researchers. It can potentially become a shot in the arm for the Indian Human Space Program. Apart from research, the tourism boost that such a site can give will also benefit local communities.

Keywords

Analogue research; terrestrial research station; Martian; Lunar; Ladakh

India has set ambitious targets for space. The Indian Prime Minister formally announced the Indian Human Space Program on August 15, 2018. The Gaganyaan program seeks to place Indians in space on an indigenous vehicle. Towards this end, ISRO has formally inducted four astronaut designates into its ranks on 27th Feb 2024 when the honorable Indian prime minister awarded astronaut wings to them. Besides the Gaganyaan program, India has signaled its intentions to have its space station, the Bharatiya Antariksha Station (BAS), and put an Indian on the Moon by 2040. India's plans for exploring the solar system extend beyond the Moon to Mars. The Mars Orbiter Mission 1 (MOM 1) of 2014 was ISRO's first mission to Mars, and follow-up missions have already been announced. While MOM 1 was an orbiter-only mission, future missions will likely involve rovers. These announcements signal the human space program's continuity; hence, India must work stridently towards developing infrastructure to support such a program. A key concept in furthering new technologies is the concept of extra-terrestrial habitat simulation. Such habitats are the critical first step in evaluating designs, testing materials, training personnel, and performing scientific studies. Analogue habitats also allow for the collection of significant data and the implementation of test cases with varying parameters. Simulation tests are essential for extra-terrestrial habitats, as these habitats are meant to be stand-alone units capable of handling all contingencies. A necessary condition for a successful extra-terrestrial space program is the setting up of simulation facilities where scientists can collect data with Indian personnel and help provide inputs for future designs. Creating extra-terrestrial analogue habitats is crucial for supporting prolonged space missions and addressing the challenges of

sustaining human life outside of Earth. It is also imperative that these habitats are analogous, both in design and proposed locations, as accurately as possible for meaningful lessons.

India has several locations with diverse environments (deserts - cold and hot, caves, mountains, ocean/seas) that can serve as natural laboratories and training grounds to support upcoming Mars and Moon missions and for research. Isotopic measurements have revealed that the Earth and the Moon are made of the same minerals, with the difference being that Earth is a dynamic and 'alive' planet, while the Moon is still and 'dead'. Earth's surface is constantly changing due to the movement of crustal elements due to several endogenic and exogenic forcings. On the other hand, the Moon's surface is mostly still, with no wind and traces of water in its polar regions. Finding an appropriate area for the Moon analogue is complex, while Mars, which is a terrestrial planet like the Earth, has several analogue sites. Table 1 lists a few of the numerous potential sites in India which can serve as experimental and functional analogue sites for Mars. Nevertheless, the vast flat lands of the high altitude, cold, arid desert can serve as the Moon analogue, too. Researchers have also described Ladakh as having a Lunar topography; hence, in India, Ladakh can also serve as an analogue site for the Moon to test its future human-crewed missions. Ladakh can serve as both a lunar and a Martian analogue site.

Table 1: List of some potential Martian analogue sites in India

SNo	Site	Relevance/study
1	Ladakh	Extremophiles (thermo, halo, psychrophiles), cryosphere & permafrost, geomorphology, geology, biology, microbes, lake sediments, volcanic rocks, instrument testing
2	Craters (Lonar, Dhala, Ramgarh)	Impact activities
3	Rann of Kutch	Halophiles, geology
4	Arabian Sea, Bay of Bengal and Indian Ocean	Deep sea studies of fans, corals etc.
5	Caves (Meghalayan caves)	Stalagmites, stalagtites
6	Volcano (Barren Islands)	Volcanic features
7	Deep mining sites	Life in extreme conditions

Internationally, various countries have developed significant scientific capabilities regarding human space programs through ventures such as the International Space Station (ISS), analogue missions such as BIOS-3 (Russia), HERA (NASA, USA), Biosphere 2 (USA), MARS-500 (Russia) and others. While ISRO has demonstrated considerable scientific and engineering capabilities in rockets, satellites, propulsion systems and space applications its exposure to humans in space is developing. Whenever a nation pursues a human space program, it becomes essential to simulate all aspects of the mission during transit and at extra-terrestrial locations. India is not a part of ISS or any of the analogue missions (see Table 2). Due to obvious reasons, human space programs necessitate simulations on the ground. Thus, analogue habitats are a vital component of any human space program. Moreover, such habitats can also serve as research stations for a diverse set of researchers who can complement the program. For example, a habitat situated in Ladakh can become a research station to study various extremophilic and extremotolerant life forms.

There are two significant aspects of an analogue habitat. The first aspect concerns providing a setup for mission component studies such as testing of new equipment, habitability studies and cognitive studies.

The second aspect concerns conducting experiments in an analogous environment and thus functioning as a research station. Thus, an analogue habitat can double up as a research station while also serving as a precursor to the actual exploration of an extra-terrestrial body. In recent decades, approximately two dozen simulation habitats have been constructed across various locations worldwide (Figure 1). Table 2 lists some of these. Several of these habitats have been designed specifically to replicate certain aspects of life on Mars (such as HI-SEAS) or the Moon (e.g., Lunar Palace 1). Others serve as active research stations that incidentally resemble planetary surface habitats and are thus utilized accordingly. An analogue habitat is helpful in the following ways:

- As a testing platform for relevant technologies
- Advancing TRL levels
- Engineering integration
- Human studies
- Crew training
- Research (geological, geomorphological, habitability, life detection etc.)

Table :2 Some Analog Habitats

Name	**Location**	**Year of Operation**	**Comments**
BIOS-3	Krasnoyarsk, Russia	1972	Closed-loop biodome located at the Institute of Biophysics in Krasnoyarsk, Russia. Habitable volume ~ 315 m^3. (Bios-3)
HERA	Johnson Space Center, USA	2014	Two-story, four-port habitat. Volume of 148.6 m^3 – (HERA)
Biosphere 2	University of Arizona, USA	1991	3.14-acre structure built to be an artificial, materially closed ecological system. (Biosphere-2)
LunAres Research Station	Poland	2017	Private analog laboratory for simulating crewed space missions. (LUNARES)
MDRS	San Rafael Swell of Southern Utah, USA	Early 2000s	Private property developed for research. Has multiple observatories and also an analogue habitat. (MDRS)
Mars One	Netherlands	2011	Private initiative. Closed in 2019.
SHEE	Europe (transportable)	2016	Self-deployable portable habitat for extreme conditions
D-MARS	Israel	2018	Analogue habitat in a desert.

The global map of Analogue research stations features 33 stations (Preston et al., 2014); none are in the Indian sub-continent. Given the Indian plans to have a space station by 2035 and a Moon landing by 2040, India must prioritize establishing multiple analogue research bases/stations. India, with its varied topography has several highly qualified sites for setting up of analog habitats. In this paper, we propose Ladakh to be the first site for the establishment of an analogue habitat/ research station.

Why Ladakh? Our observations show that the Ladakh sector of the Trans-Himalayan region in India is one of the best sites for developing an analogue research station. It is a dry, cold, arid desert, has abundant rocky ground, loose rock blanketing the mountain slopes, vast flat land, segregated ground ice/permafrost, rock glaciers, dunes, drainage networks, and catastrophic flooding and even dust devils making it geomorphologically similar to an early Mars and Moon (Table 3). Hanley's dark skies in Ladakh are also a major astro-tourist attraction. The volcanic rocks and serpentinite exposures, the saline lakes, and the active and hydrothermal systems can give a clue to the processes and chemistry of the Martian grounds (geochemical fidelity).

Regarding exobiological fidelity to Mars, the permafrost (evidence of water in the past), increased UV and cosmic radiation flux, reduced atmospheric pressure, and hot springs (some rich in boron) are some examples. The enormous flat land devoid of vegetation in this high-altitude region and the igneous rocks of the Ladakh sector can also be a good analogue for the Moon. Rai et al. (2009) have reported multi-shelled orbicular olivine gabbronorite with anorthositic rims from this region. More research in this aspect can give a better understanding of the Moon's surface, geology, geomorphology and underlying processes. Prasad et al., (2024) described conditions are suitable geologically, climatically as well as physically to our Moon. Though the area is naturally not rich in craters, the same can be created as was done for Apollo missions at the Black Point lava site and Cinder Lake site. At these sites, craters were created to test out rovers, vehicles, equipment, and training of astronauts. Sufficient isolation of the place also encourages the feeling of self-sufficiency and survival among the crew, a requirement for actual missions.

Table 3. List of features of Ladakh as Geochemical, Geomorphological, Astrobiological Climatic fidelity/comparison and Analogous to Mars and or Moon

Characteristics / **Name**	Geochemical	Geomorphology	Astrobiology	Climatic	Analogous
Ladakh					
Ladakh Dry Valleys	Mars	Mars/ Moon	Mars/ Moon	Mars /Moon (Polar Regions)	Mars & Moon
Palaeo-lake sediments	Mars	Mars	Mars	Mars (Polar Regions)	Mars
Hot springs	Mars	Mars	Mars	-	Mars
Igneous and volcanic rocks of Ladakh	Mars/ Moon	Mars/ Moon	Mars/ Moon	-	Mars & Moon
Catastrophic flooding	Mars	Mars	Mars	-	Mars
Periglacial processes	Mars	Mars	Mars	-	Mars
Glacial processes	Mars	Mars	Mars	-	Mars
Aeolian features	Mars	Mars	Mars	-	Mars
UV affected surface	Mars	Mars	Mars	-	Mars

Hence, the Ladakh environment, characterized by its sub-zero temperatures, limited precipitation, rivers and lakes, comparatively low atmospheric pressure, hot-water springs, and relatively high ultraviolet flux,

is an analogue for Mars and the Moon. Ladakh is a treat for geographers, geologists, and in recent years also for the astrogeologists and astrobiologists and for developing astrotourism; its lunar/martian landscapes, exposures of sedimentary, metamorphic, and igneous rock types; glacial, fluvial-lacustrine sediments and active climatic and tectonic processes make Ladakh unique. The glacial passes, dunes, hot springs and saline lake sites in Panamik, Puga and Tso Kar regions of Ladakh for their astrobiology potential have been highlighted by researchers (Pandey et al., 2019; Phartiyal et al., 2021; Chakraborty et al., 2023). Hence, Ladakh can be chosen as an appropriate site for developing the Indian Research Analogue station for Mars and the Moon.

Scientific simulation provides scientists and engineers with adequate conditions for testing and studying. Depending on the research purpose, the required environment ensures various controlled and recurring conditions and data for comparison in the analogue research station. The analogue research station can provide the physical infrastructure to support on-site sample storage and processing. For example, small equipment and consumables, such as refrigerators/ice boxes for sample storage, microscopes, slides, and chemicals for maceration/tests, can be housed there. An analogue space station is relevant in undertaking astrobiology, astrogeology and space biology experiments, including engineering tests. Eventually, astronaut candidates can also use the site as a prolonged stay habitat station, where scientists can undertake behavioral and other relevant studies. In addition to all the reasons mentioned above, the analogue station can also be utilized for outreach and educational activities.

Figure 1. Photograph of the Flashline Mars Arctic Research Station, Scientist working in Isolation; Testbed for instrument testing (Picture Credits: Anushree Srivastava)

What are some of the research topics that can be immediately taken up at such a station? One low-hanging fruit would be research in extremophiles. We note that India has research bases at both the Poles (Antarctic and Arctic). Samples from the poles can be compared with samples retrieved from Ladakh. A direct comparison between the preservation and sustainable exploration of astrogeological and astrobiologically relevant sites in India and Antarctica can be made. Thus, research in extremophiles and extremotolerant organisms is one of the first research activities that can be taken up at a Ladakh-based analogue research station. From an engineering perspective, an analogue habitat can provide fertile testing grounds for human space technology and boost the TRL levels of prototypes. A proposed engineering habitat design utilizes the concept of modularity, which allows the habitat structures to be easily assembled and expanded as required (Figure 2).

Currently, analogue missions are being organized by space agencies as well as private entities and researchers. NASA and ESA's strong partnership with private entities in various aspects of space program show how the private sector's capacity and faster working process benefit governmental agencies. In 2016,

NASA's Spaceward Bound (Spaceward Bound) India programme was conducted in Ladakh. A team of scientists, educators and students worked on several pilot projects to name some - Field Validation of ExoMars 2020 HABIT Instrument, Hot Springs - the Origins of Life & Carbon Metabolism in Hot Spring Thermophiles; Microbial Life in Tso Kar Salt Flats and Shorelines; Placement of Artificial Hypoliths to study microbial growth; Regolith landform mapping in cold climates along with Outreach and Teacher Training in Local School (Pandey et al., 2019). Hence, in Ladakh, we can have an analogue Research Station that is accessible for researchers from all over the country wanting to do space science and analogue research, It is accessible all year round, and it offers unique capabilities for maintenance and usage with resilient support and self-sustaining.

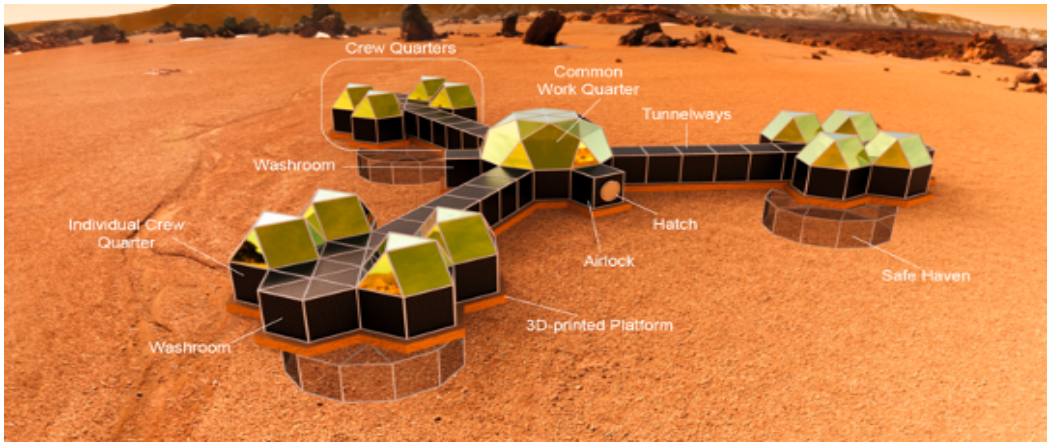

Figure 2: An initial design of an analog habitat by researchers from the Indian Institute of Science. Image adapted from Baruah et al., 2024.

India has a rich geographical landscape, and Ladakh has a unique position. The time is ripe for establishing an analogue station in this region, benefiting a diverse group of researchers. It can potentially become a shot in the arm for the Indian Human Space Program. Apart from research, the tourism boost that such a site can give will also benefit local communities. We believe that such an effort is a necessity and must be addressed on priority.

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